An Electron Calorimeter for the TeV Observations at the Japanese Experiment Module on International Space Station

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Abstract

We propose a precise measurement of the electron energy spectrum in TeV region. at the Japanese Experiment Module Exposure Facility (JEM/EF) on ISS. Since the TeV electrons could be reached only from the nearby sources within a distance less than 1 kpc, it is expected that the energy spectrum has a structural component and distribution of the arrival directions presents anisotropy. Therefore, we can localize and identify the nearest cosmic ray sources by these measurement. We report status of the development of an imaging calorimeter for the observation, which has a proton rejection power in excess of 10^5 and a geometric factor which is enough to observe more than a thousand events over 1 TeV for 3 years observation.

1 Introduction:

Electrons in cosmic-rays have unique features compared with other components. Since they lose energy in proportional to the square of the energy in the Galaxy, the life time of electron becomes shorter when the energy increase and the propagation distance reduces. In the TeV region, only the electron from the sources at a distance within 1 kpc with ages less than $\sim 10^5$ years can reach on the Earth. Since the number of such sources are very limited, the energy spectrum of electrons should have a structure and the arrival direction are expected to have an anisotropy. Therefore, if enough data in TeV region are given, we can directly identify the sources where the electrons were accelerated. Value of the diffusion coefficient can also be determined as the electron fluxes depend strongly on the the propagation parameters(Nishimura *et al.* 1997, Aharanian *et al.* 1995).

However, at present, we have no detector to measure the TeV electrons with enough statistics. The reason is the difficulty of electron selection among the copious background protons (say, 10^3 times larger) and of the energy measurement. An instrument used below 1 TeV has enough hadron rejection power in excess of 10^5 using combination of a Transition Radiation Detector (TRD) or a Ring Imaging Cherenkov (RICH) detector, a magnet spectrometer and a shower counter (Barwick et al., 1997, Barbielline et al. 1997). It is, however, can not be used over 1 TeV since the TRD and RICH is not valid for electron selection and the MDM of magnet is limited below 1 TeV/c. Only emulsion chamber has successfully detected the electrons over 1 TeV (Nishimura et al., 1980). Although an exposure over one year to the cosmic radiation is necessary to observe enough statistics, it is difficult to use emulsion chamber for the exposure because of accumulation of background tracks and flooding by lower energy electrons.

Among few candidates of the detector, an imaging-calorimeter with fine segmentation is promising to achieve the measurement of TeV electrons. In the following, we shall report our development of an electron calorimeter aiming an observation at the Japanese Expereiment Module Exposure Facility (JEM/EF) on the International Space Station (ISS).

2 JEM Exposure Facility:

JEM has a unique facility for exposed detectors as presented in Fig.1. The JEM/EF has 12 attached payloads with a size of 1.85 m × 0.8 m × 1.0 m for each. The weight limit for standard payload is 500 kg and one heavy payload which can be mated to either EFU#2 or #9 has a maximum limit of weight of 2,500kg. We propose an electron detector at one of the payloads. At present, as a basic idea, a standard payload is considered to be used although the use of heavy payload is required.

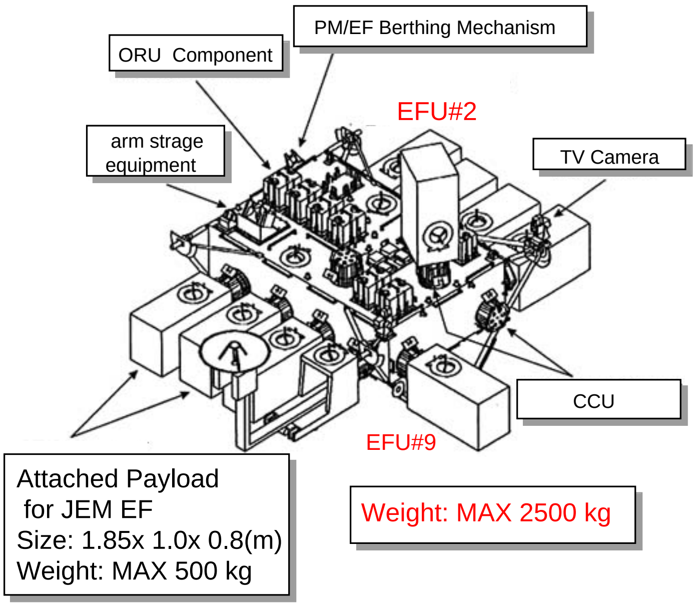

Figure 1: A schematic view of JEM/EF and the attached payloads.

3 Basic Design of Detector

The basic idea of detector was obtained from a balloon payload. The payload with an acronym of BETS (Balloon borne electron Telescope with Scintillating fibers) was developed for measuring the electrons from 10 to several 100 GeV (Torii *et al.*, 1999a Torii *et al.*, 1999b peper OG 1.1.15). The BETS instrument uses a unique technique for shower imaging to discriminate electrons against the background protons (Torii *et al.*, 1997 Tamura *et al.* 1999 paper OG 4.1.6).

3.1 Imaging Calorimeter The detector is a scitillating fiber and lead sampling /Lead imaging calorimeter with an area of 50 × 50 cm^2 consisting of 23,000 scintillating fibers and 13 r.l thickness of lead. Each fiber plane is made of 500 fibers with a 1 mm square cross section for each.

The fiber is spliced to an optical (clear) fiber, which is used as light guide, at the edge of detector part in order to be free from the noises. Each of clear fiber outputs are split to into tabs which are stacked and bonded together. Four sets of the fiber outputs are routed to each of an image-intensified CCD camera for read out. The CCD camera has an input window with a diameter of 10 cm and has a "shutter" function which is operated by a gate signal from the trigger system. Two cameras are used for each direction; four cameras in total. For calibration, LED lights are irradiated to the camera through clear fibers. The performance and general characteristics of the payload is summarized in Table 1. Since the electron flux over 1 TeV estimated from the power index of -3.3 is nearly 2 /m^2 $\cdot$ $sr$$\cdot$day, the expected number of electrons over 1 TeV for the 1000 days exposure is about 1000.

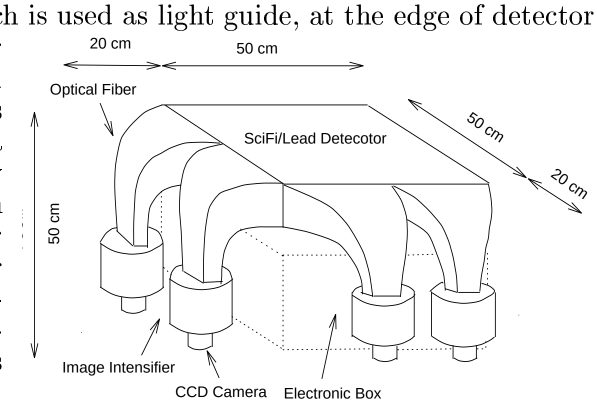

Figure 2: Schematic view of the electron telescope for the JEM experiment.

Table 1: Instrument performance summary

Energy Range (GeV)	10 $\sim$ several 1,000
Geometric Factor (m^2 sr)	0.5
Proton/electron Discrimination	$\sim 10^4$
Energy Resolution (%)	≤ 15
Angular Resolution (degree)	0.7 $\sim$ 1.2
Weight (kg)	$\sim$ 300
Power Consumption (W)	≤ 100

3.2 Hardware Development The development of hardware is carried on for the image-intensified CCD camera, the read-out electronics and the scintillating fiber fabrication. The camera in space quality is developed in co-operation with Hamamatsu Photonics K.K. It is required for the camera that it must keep the function under the vibration of 12 G for 180 secs. The dynamic range should be from 1 MIPS to a few thousands. As an alternative of read-out device, we are trying to use the 64-anode compact PMT (R5900-00-M64, Hamamatsu) with a read-out system of VLSI chip. A scintillating fiber belt of with a connector to the clear-fiber guide is fabricated for the environment test.

4 Detector Concept for Heavy Payload Option

For the current design of detector of the standard payload. the proton rejection power is expected to be nearly 10^4 by a neural network analysis of Monte-Carlo simulation events However, in order to do the electron measurement in any case of the expectations from different models, it is required to achieve a rejection power of one order higher, say 10^5. For the purpose, we are considering an alternative of detector for heavy payload.

4.1 Detector Concept We have designed a type of calorimeter in Fig.3 which adopts to requirements for the heavy payload attachment. The proton rejection power is studied by Monte Carlo simulation.

The calorimeter is composed of two part. One is an imaging calorimeter as that for standard payload. The thickness of lead is 13 radiation length (r.l.) and 24,000 fibers are used as sensitive layers. The other under the imaging calorimeter, has a total absorption calorimeter consisting of 2.5 cm *times* 2.5 cm *times* 30 cm BGO logs. The BGO calorimeter is used mainly as a hadron rejector. The logs are placed in right angles layer by layer to get information of two dimensional development of shower particles. The total thickness is about 45 r.l. and 2.1 mean free path (m.f.p.) for protons. From this design, it is possible to measure the full development of electrons up to 10 TeV and to detect a part of interactions of secondary hadrons. This capability with fine imaging of showers the imaging calorimeter might give us a rejection power better than 10^5.

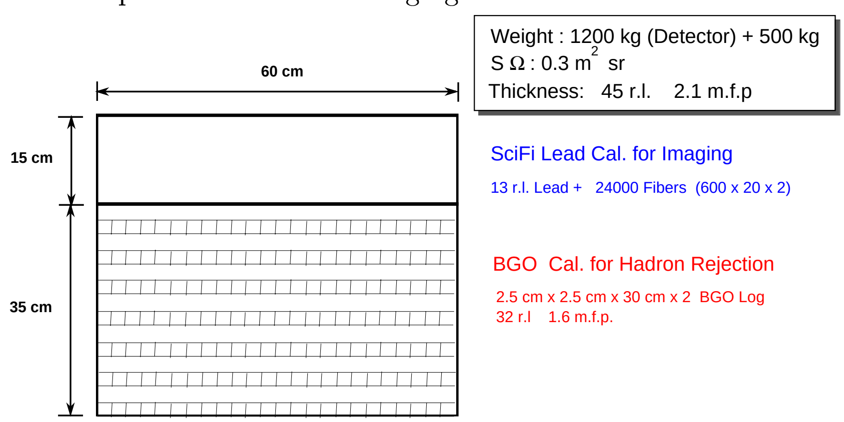

Figure 3: Conceptual side view of the calorimeter for heavy payload.

4.2 Simulation In order to optimize the BGO thickness, we used a BGO calorimeter with a thickness of 50 cm. Except the thickness, all other configurations are same with the model in Fig.3. We recoded energy deposition in each fibers and in BGO logs for electron events with an energy of 0.1 TeV, 1 TeV and 10 TeV and for proton events with 0.3 TeV, 3 TeV and 30 TeV. All particles enter from the top of detector at the center with the vertical direction. Protons with an energy of three times larger than electrons are compared as the background of these electrons. Simulated number of the electron events are nearly 1,000 and that of protons is typically 10,000.

After selection of the showers which start within 6 r.l. thick of lead in the upper imaging calorimeter, the energy deposition in BGO calorimeter are obtained for electrons and the background protons. Figure 4 shows a comparison of the distribution of the energy depositions for 1 TeV electron and 3 TeV proton. As clearly seen in the figure, the separation becomes better when the depth becomes larger. At the depth of 32.5 - 35 cm which is the depth of model in Fig.3, only one proton among 10^4 events is mistaken to be electron while 90 % of electrons are remained. This event could be removed by an imaging analysis used in BETS. The results for 0.1 TeV and for 10 TeV is much better and no protons can not be mistaken.

It is easily estimated if we will apply an imaging analysis for showers, the rejection power can be in excess of 10^5 up to 10 TeV. At the conference, we will report the results of total rejection power including imaging analysis by the use of simulation events with higher statistics in number. It is easily supposed the material for the calorimeter is not necessary BGO if the total thickness of calorimeter of nearly 50 r.l. and 2 m.f.p. However, the imaging calorimeter composed of scintillating fibers for fine segmentation and lead (or tungsten) for separation of starting points are indispensable for the electron measurements.

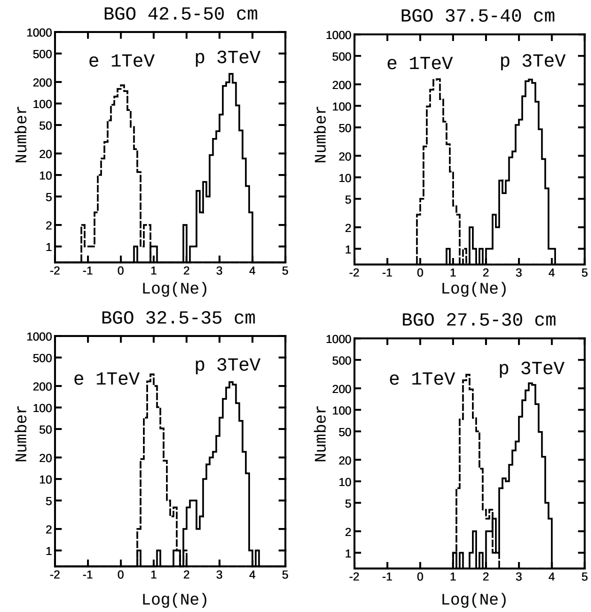

Figure 4: Simulation results for the distribution of deposited energy sum in the BGO logs at each depth. The dotted line is 1 TeV electron and solid line is 3 TeV protons.

5 Summary and Discussion:

We are developing an imaging calorimeter as a unique option for the the TeV measurement. Although we need more study on the design and the hardware development, an imaging calorimeter with scintillating fiber is promising to achieve the electron measurements. We will try to launch the instrument on the JEM/EF around 2006

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